Design & Analysis of Grid Tied Single Stage Three Phase PV System

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Abstract - *Renewable energy resources are very fashionable and popular for green energy and very widespread used nowadays. The usage of PV systems has risen as fossil fuel supplies have declined and photovoltaic cell costs have decreased. Even though PV panels are inexpensive, MPPT methods are still popular for controlling power electronic converters. Solar cells make up a photovoltaic system that convert light into electricity. A single small PV cell can produce around 1 or 2 watts of electricity that depends on what kind of raw material is used to make that PV. PV cells are sometimes wired together to create higher power modules for higher performance. Because of using PV as a source of renewable energy, Inverters, for example, have been commonly used devices for this purpose, and various approaches have been proposed to get the most generated power from a PV device to date.*

This paper makes a proposal for a 50kW single-stage solar system which is PWM based DC-AC converter with three-phase grid connection with a combined power of 53kw at 1000w/m² irradiation by using 21 series and 11 parallel panel strings, a device built to process energy from a photovoltaic array made up of SunPower SPR-230E-WHT-D PV module for any solar radiation with a high-power factor. This paper introduces a control strategy for Photovoltaic generation systems with a three-phase grid connection and utility power factor in any circumstance of solar radiation using Park's transformation (dq0 transformation) which operators with current control mechanism to increase power efficiency. Loads attached to the device produce reactive power and harmonic components that can be compensated by the system.

Key Words: Photovoltaic cell, Maximum power point, Inverter, Renewable energy sources, Power system.

1. INTRODUCTION

Many concerns have arisen as a result of the use of fossil fuels as a primary source of power production. In terms of power generation, India ranks sixth. Thermal power plants produce approximately 65 percent of India's energy, while hydroelectric power plants generate 22 percent, nuclear power plants generate 3%, and other alternative sources such as solar, wind, and biomass generate the remaining 10%. India's large coal reserves have 53.7 percent of the country's commercial electricity demand [1]. The use of green technology, such as a solar energy system, is often used to remove or mitigate such problems. The most serious problem associated with the use of fossil energy is global warming, where the rise in fossil fuels such as oil and natural gas are used to generate electricity through several decades resulted a number of environmental as well as health issue.

Solar cell-based photovoltaic power generation that is ready to direct conversion of solar energy to DC Electricity has the potential to be a clean energy source and It can be broadly pertinent renewable energy source accessible for forthcoming energy production. As a result of photovoltaic processing developments over the last few decades, the participation and role of electric utilities in PV has increased significantly. Observations on the inverter's DC side are needed thus to measure and sustain tracking, MPPT algorithms are used for the highest operating point at every instant. Numerous approaches have been found and discussed in this decade in order to reduce or to get rid of these measurements, the system's complexity is minimized, and it is more cost-effective.

The DC/DC converter controls full output, while the DC/AC converter synchronizes and feeds required power to the grid in a two-stage topology, is one of many approaches for a sensor-less MPPT algorithm. [3-5]. However, such strategies necessitate at least one calculation, such as current or voltage on the DC side of the converter, as well as a large number of power switching instruments. Other methods, on the other hand, use a one stage converter topology, which has the benefit of reducing the number of conversion steps and power switching units. There has been a decrease in a number of sensing elements in one stage topology, and On the DC side of the converter, MPPT algorithms need at least one sensing component, which involves filtering the calculated values to have the DC quantities on average, necessitating more computing power from the controller, and it was suggested for the MPPT algorithm to work based on only measuring PV panel current [6-12].

There are various research work going on the power quality enhancement of PV systems such as elimination strategies or harmonic compensation. When the generated electrical power from the renewable energy resources is supplied to grid through the grid connected inverter, the inverter should be providing zero steady-state error, fast response, and robustness to disturbance. In addition to that the grid-connected inverter should effectively compensate the imbalance in the system, reactive power, and harmonic. Conventionally, the simple PI control is used to regulate the grid-connected inverter. The distortion caused by harmonics under the distorted grid cannot be adequately compensated using the PI controller.

Henceforward, this paper presents a grid connected PV system and the control strategy of the inverter and that is based on control of active and reactive power using Park transformation or dq0 transformation in three phase grid connected PV system. The MPPT based controller for DC-AC converter is designed in this paper using Perturb and Observe.

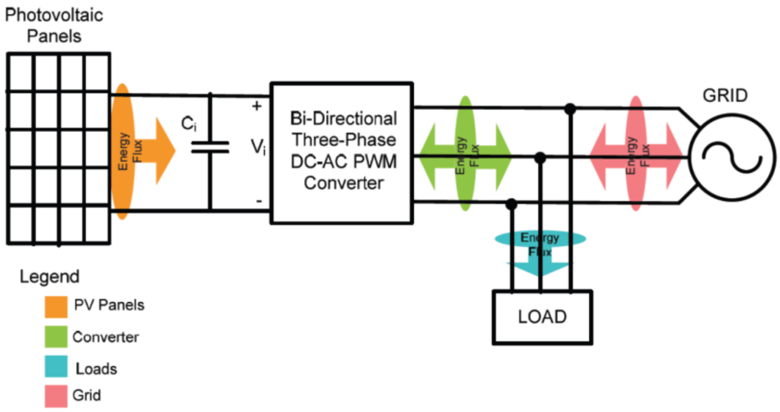

Figure 1: Proposed three-phase photovoltaic power system.

2. PHOTOVOLTAIC ARRAY MODELLING

We can say that a solar cell is a kind of p-n junction diode that generates the charge carriers when the intensity of an incoming photon exceeds the semiconductor component's bandgap. Many PV cells are attached in series and parallel to form a photovoltaic module and A photovoltaic array is a series or parallel interconnection of modules made up of several PV cells to attain the desired power. The model is ideally suited for the scientific conditions because it includes a series and parallel resistance as well as the observation of the terminal voltage.

The general equation for an individual solar cell is:

$$I = I_{pv} - I_0 \left[e^{\left(\frac{qV}{akt}\right)} - 1\right] \quad (1)$$

Here "I" represents current from an individual solar cell, The total current produced by solar irradiation is denoted by "I_{pv}", the reverse saturation current or leakage current of the diode is denoted by using "I_0", "a" denotes the ideality factor of the diode, which denotes the correction needed to conform the calculated values to the theoretical PN junction characteristics of a solar cell; the temperature of a diode in Kelvin "T", the charge of an electron can be represented by "q" and "k" is the Boltzmann constant.

Eqn (1) does not adequately depict the features of a realistic solar cell. The model is ideally suited for the analytical situation with the inclusion of a series and in parallel resistance as well as the analysis of the terminal voltage.

$$I = I_{pv} - I_0 \left[e^{\left(\frac{V+IR_{(ser)}}{aV_{(t)}}\right)} - 1\right] - \frac{V+IR_{(ser)}}{R_{(per)}} \quad (2)$$

Where, "R_{ser}" specifies the total series resistance of all the solar cells connected, "R_{per}" specifies the total parallel resistance of solar cells connected, "V_t" is the terminal voltage which can be calculated as "$V_t = kT/q$" and "V" is the terminal voltage of combination of solar cells, and "R_{ser}" exists due to the contact resistance between the connection terminal and the solar cell, whereas the p-n junction's leakage current gives rise to "Rper." The amount of parallel and series variations of solar cells used to create a PV array can be modified using Eqn (2). The voltage in a PV array can be increased by raising the series cell in the module, while the current level can be increased by increasing the parallel cells in the module. In this paper a PV array using SunPower SPR-230E-WHT-D was used to validate the proposed methodology.

3. SYSTEM MODELLING & CONTROL METHOD

Typically, the first stage of this power system is applied to boost up or increase the value of voltage; however, having a two-stage power layer boosts the system's overall cost. Instead, single-stage power converters were proposed as a way to cut machine costs but, to increase the DC bus voltage, a series-connected panel group is necessary. Even though numerous solutions for increasing DC bus voltage have been suggested, in which applying a single-stage power layer operation with series-connected PV panels is the most popular method. [13-15].

Inverters are divided into four groups depending on their output waveform: square wave, multilevel, sine wave and modified square wave. The converter modelling is straightforward, relaying on six IGBTs in the circuit. It is important to obtain current and voltage modelling for the desired output in order to implement the proposed technique. Figure 2 depicts a simplified electrical diagram of the converter. Pulse width modulation is a technique for adjusting the frequency of pulses in response to a small control signal in a pulse train.

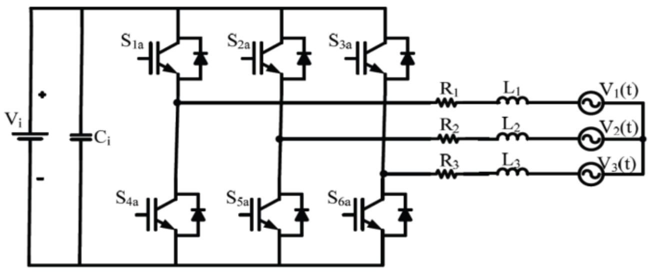

Figure 2: Bi-directional DC-AC PWM based inverter.

Inverters with three phases are typically used in applications of high-power. Figure 1 demonstrates a general circuit system and control techniques. A three-phase power inverter connects the PV panel device along with the grid directly. Eqns. (3) and (4) can be used to measure the inductance and capacitance of the LC filter, respectively.

$$L_f = \frac{0.1U^2}{2\pi f P_p} \quad (3)$$

$$C_f = \frac{0.05P_p}{2\pi f U^2} \quad (4)$$

The converter's bi-directional functionality is crucial in this proposed photovoltaic device because depending on the application, active and reactive power must be processed from the generator to the load and vice versa. Thus, the active and reactive power flows can be regulated with careful monitoring of the power switches. The inverter goes from one point out to another state to produce a waveform. Since current output has harmonics, an LC filter is used to minimize these harmonic distortions in the output current. For maximum power point tracking in a PV system, perturb and observation methods are used.

A. CONTROL SCHEME

The idea of current control simulation is to obtain the active input current clamping $I_i(t)$. This active clamping makes following advantages to the system:

- Power flow management between the grid and the solar PV facility.

- And the Possibility to realizing MPPT of the PV panels.

By using P&O method for the MPP tracking in the PV system and it is noticed that voltage values vary very little with time, the difference in solar irradiation intensity undergoes significant changes. In India, most of the places has no important and large temperature variation during the day.

The MPP approach is based on the most recent system of control and that is achieved by maintaining the voltage constant and close to the MPP in the PV terminals. An example is presented below for the current properties and voltage properties of a PV cell for various values of irradiation.

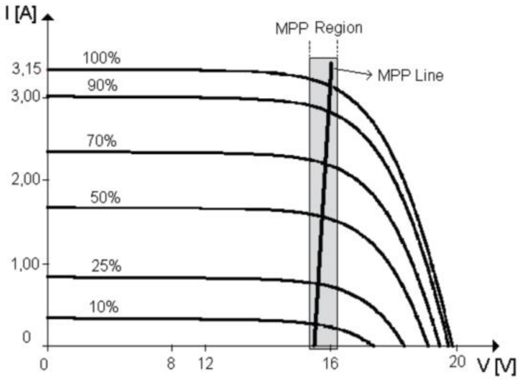

Figure 3: An Example of characteristics between Current and Voltage of a PV cell.

Keeping an eye on the MPP points and forming an MPP Line by linking them, it is seen and noticed that and as the rate of solar irradiation varies greatly, the voltage values remain relatively constant. In terms of temperature, there is no significant difference during daytime. When the voltage is kept "within" the MPP region, when the irradiation increases, the amplitude of the PV cell's current changes as well; however, the PV cell's output voltage is not affected significantly.

4. IMPLEMETATION OF THE CONTROL

Figure 4 depicts the proposed grid-connected three-phase PV system's MATLAB model, control methodology, and modulation. As from Figure 4, output currents I_a, I_b and I_c from the inverter are obtained, and it is applied to Park's transformation by this I_d and I_q are obtained and used for active power and reactive power control in the system.

A reference current Iref is generated from the MPPT algorithm through the PV current and PV voltage. Because of the reference current value changes based on MPPT algorithm, the value of output current from the inverter varies in response to the irradiation curve. An error is generated through the Iref and I_d for the active power control. The inverter currents efficiently follow the reference value Iref which is obtained by the algorithm. The Proportional Integral (PI controller) controller is the very popular controller used for providing feedback and error compensation. PI controllers are used to calculates an error value which is basically is the difference between measured current obtained from the inverter as an output and a desired injected current, the controller then makes an effort to reduce the error coming between them. Kp represents the proportional coefficient and Ki represents the integral coefficient, these are two autonomous constant parameters in the PI controller. The signal generated from error is multiplied by a Kp coefficient to form the proportional term of the controller. In time, this helps to reduce the overall error. The proportional coefficient, on the other hand, will not be able to reduce the error to low as zero, and there are always some steady state error present in the system. To minimize small steady state errors the Integral coefficient of the controller is used. This eliminates the steady state error and speed up the effort of the process into the reference point and Id_ref is obtained. With the same process Iq_ref is obtained but with zero reactive power as input value. Changing the direct axis and quadrature axis currents will regulate the output energy and power factor.

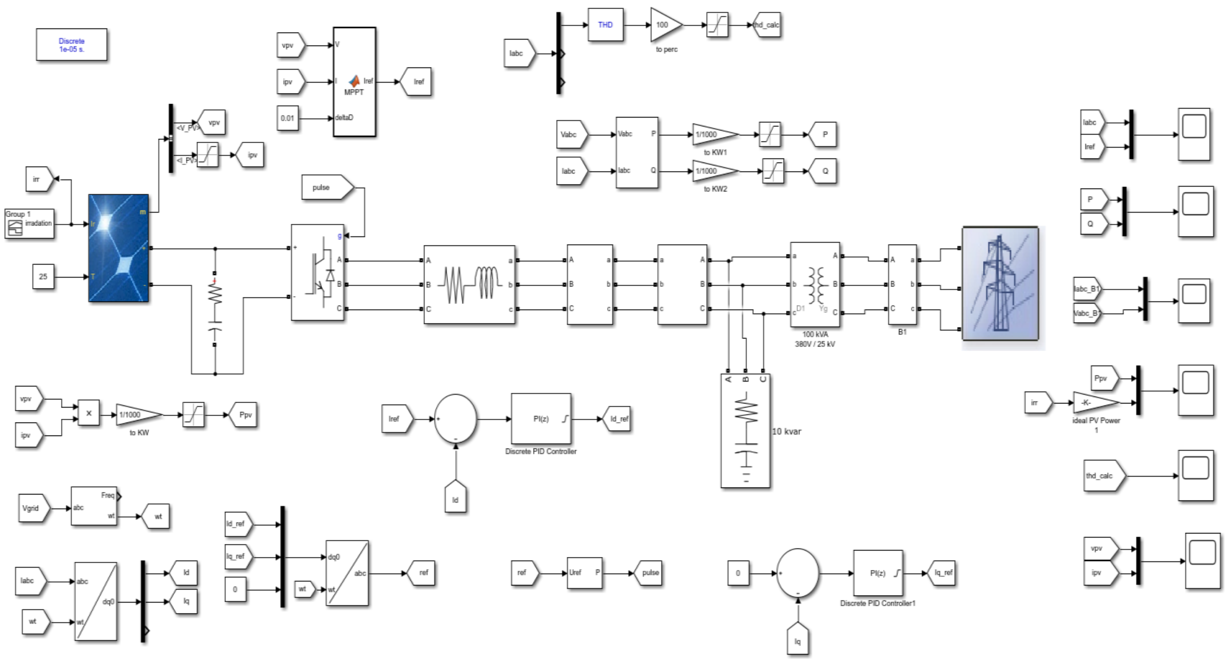

Figure 4: MATLAB Model for the Proposed System

The benefits of PI current control include a good steady-state reaction with a constant switching frequency, low current ripple, and well-defined harmonic content. We can apply PI controllers in the stationary (αβ) reference frame as well as in synchronous reference frame (dq0 frame). Whenever a synchronous PI controller is applied, the control variables become DC and the PI compensators are able to minimize the fundamental component's stationary error to zero, while when PI controllers are used in a stationary configuration, the stationary error of the fundamental component is not reduced to zero, there is an intrinsic phase and amplitude monitoring error. In three-phase grid-connected inverters, current control in a synchronous reference frame using PI controllers is the standard solution.

To compensate for the current vector elements, the inverter applied with two Partial Integral controllers, that are specified in synchronous reference frame, as seen in the above figure 4. Outputs of both the PI controllers has been converter from synchronous reference frame to abc form and named as ref in the MATLAB model, further this generated signal has been passed through the block model called Phase Lock Loop (PLL) closed-loop control system, and an internal frequency oscillator tracks the frequency and phase of a sinusoidal signal. The internal oscillator frequency is adjusted by the control mechanism to hold the phase difference to zero. The obtained waveform works as the switching pulses for the six IGBTs based three phase inverter.

5. SIMULATION RESULTS

The system model has been designed and run as per suggested control configurations in Fig. 1 and the results can be verified and supported with simulation findings. Table I lists the simulation parameters. Simulation experiments have been conducted to verify the results. The simulation considerations are described in below Table I.

Grid Voltage (U)	380 V
Grid Frequency (f)	50 Hz
Nominal Power (P)	53 KW
Filter Inductance per Phase (L_f)	6.1 mH
Resistance of Inductor (R_{Lf})	0.15 Ω

DC Link Capacitor	100 µF
Switching Frequency f_{sw}	5 KHz

TABLE 1: System Parameters

First of all, dynamic performance of the PV system consisting with a modified version of current control algorithm has been tested at various irradiation with time along with this analysis few more analysis has been done on the basis of Simulation results such as under a variety of irradiation conditions control performance of power flow in the proposed control algorithm has been tested and analyzed. Figure 5 represents the irradiation curve under varying condition. Figure 6(a) represents the output voltage coming from the PV side and figure 6(b) represents current results of the PV panel respectively. The current obtained from the PV side is rising upto 62.48 Amperes, while the PV voltage remains relatively stable. It is triggered by the nature or design of MPPT control in PV system and provides data on control output.

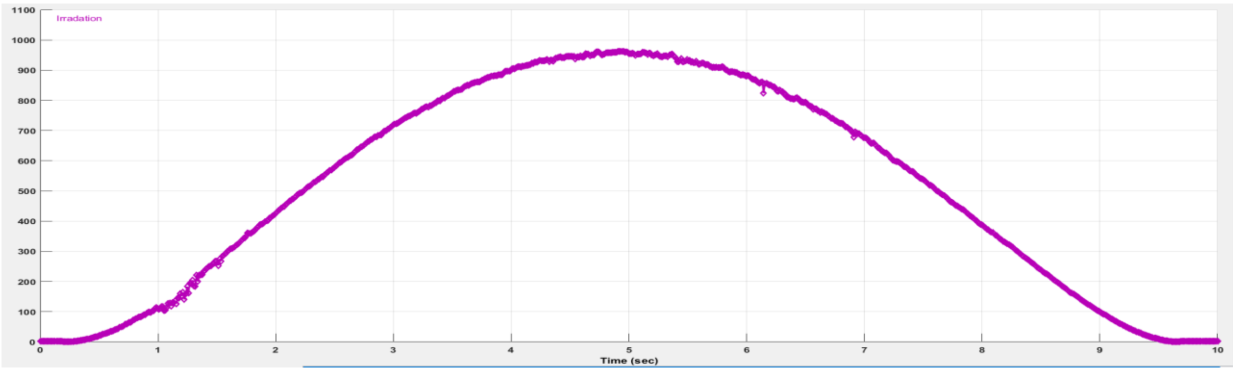

Figure 5: The irradiation curve

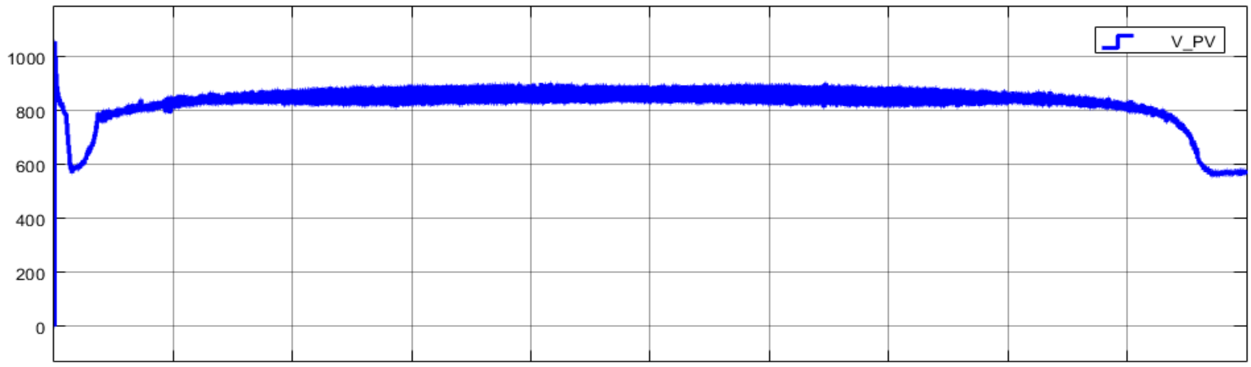

Figure 6(a): PV panel Voltage result

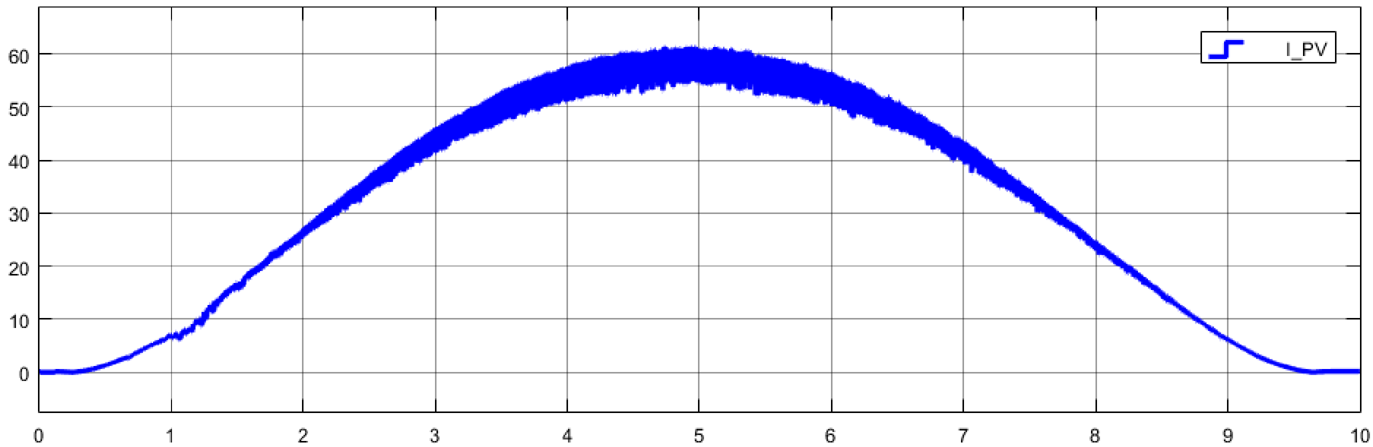

Figure 6(b): PV panel Current result

Above And Beyond the implementation test of the MPP Tracking algorithm, the inverter side is analyzed on the basis of power, efficiency, and harmonic distortions. The inverter currents are effectively and successfully following the reference value by the algorithm which is represented by Iref. The output currents of the inverter are also modified based on the irradiation curve since the MPPT algorithm adjusts the reference current value.

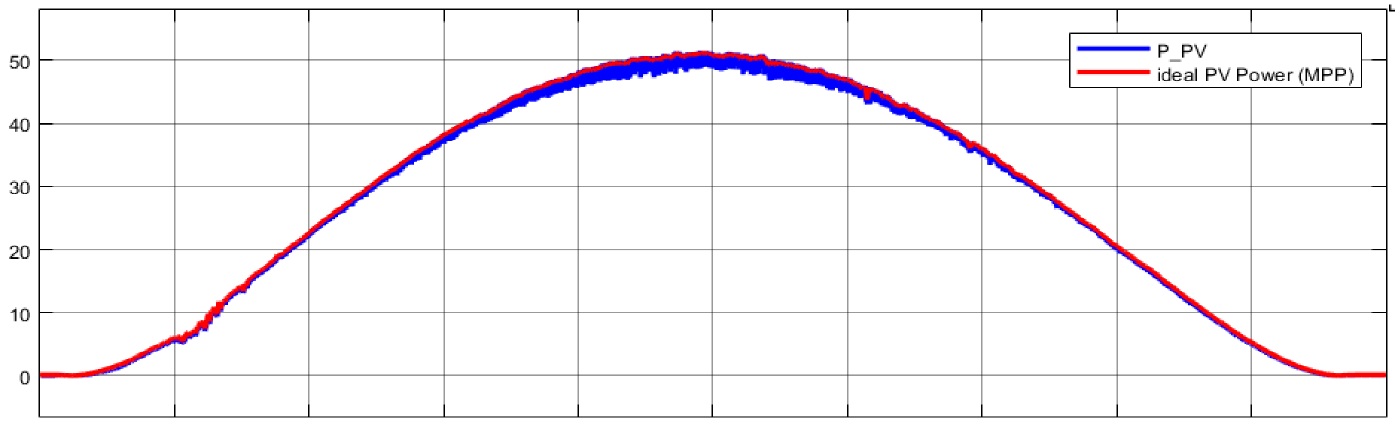

Figure 7: Comparison of the inverter and ideal MPP curves

To evaluate the overall performance of the proposed design, the transferred power to grid at the output of the inverter was compared to ideal MPP curves. Losses between the inverter output power and optimal maximum power curve has been shown in above Figure 7. Around the nominal capacity, power losses are especially high. It caused by filter inductance.

6. CONCLUSION

This article proposes a control algorithm which is basically combined form for current controlling in PV systems. MPPT algorithms and a controlling approach essentially based on the dq0 transformation was proposed for active power controlling as well as reactive power controlling of a three-phase PWM inverter to be used in a grid-connected photovoltaic generation system. The key goal of this project is to develop a dual-function system that generates solar energy while still acting as an active power filter for the system. Under changing irradiation conditions, the algorithm provided accurate monitoring.

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